

Trends in Historical Annual Flows for Major Rivers in Alberta

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Trends in Historical Annual Flows for Major Rivers in Alberta

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EXECUTIVE SUMMARY

This report presents an overview of the past and present streamflow volumes of major rivers in Alberta. The status of water resources in the Province has been discussed in various forums given recent drought conditions. As well, questions have been raised about consumption patterns and the future sustainability of Alberta's water resources under the potential impacts of climate change. This report is not intended to provide future predictions or scenarios, but instead will provide a context for understanding the current state of the resource. The historical data provided in this report covers a ninety-year period from 1912 to 2001 for nine major rivers throughout the Province. All of the rivers are affected by human activities and consumption to varying degrees, however the primary influences on annual and longer-term variability are the natural fluctuations of the hydrologic cycle. The non-parametric Mann-Kendall test for trend was applied to the rivers at a 95% confidence level. Cycles of wet and dry are prevalent in the records but significant long-term trends in natural streamflow volumes are not apparent. In all, three of the nine rivers exhibited a significant trend at the 95% significance criterion. The Peace River exhibited a positive trend while the North Saskatchewan and Beaver Rivers exhibited negative trends that were statistically significant. Consumptive use in the North Saskatchewan River may be sufficient enough to bias the analysis, which can be confirmed once a fully natural data set is developed. As well, the period of record for the Beaver River is relatively short at only 46 years and may not be truly representative of the longer-term conditions that were available for the other rivers. This may also be true for the Peace River, which has a significant data gap in the 1932-1957 period. While few significant trends were identified, of potential concern is that the trend line slope is negative in many (six out of nine) cases. Therefore, although at present there does not appear to be enough data to suggest a significant change from historical patterns, a further continuation of recent dry conditions might cause a trend to become established. In addition, precipitation records at nine sites were examined for historical patterns. In general, variability seems to be decreasing at about half of the sites but no overall trend pattern in annual precipitation totals emerged. The bias seemed to be towards slightly increasing precipitation although only two significant trends (one positive, one negative) were actually identified.

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Appreciation is also given to the past and current members of the Hydrology/Water Assessment group of Alberta Environment for their work on the South Saskatchewan River Basin Natural Streamflow Study, which provided the natural flow data that has been used in this assessment. The dedicated efforts of all the individuals involved are gratefully acknowledged.

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LIST OF ABBREVIATIONS AND CONVERSION FACTORS

Abbreviations

cubic metres per second	m ³ /s or cms
cubic metres per second per square kilometre	m ³ /s/km ²
cubic decametres	dam ³
litres	L
millimetres	mm
metres	m
square kilometres	km ²
kilometres	km
millibars	mb
cubic feet per second	cfs
cubic feet per second per square mile	cfs/sq.mi.
acre-feet	ac-ft
feet	ft
square miles	sq.mi.

Conversion Factors

cubic metres per second	×	35.3146	=	cubic feet per second
cubic metres per second per square kilometre	×	91.4646	=	cubic feet per second per square mile
cubic decametres	×	0.8107	=	acre-feet
millimetres	×	0.03937	=	inches
metres	×	3.28083	=	feet
square kilometres	×	0.38610	=	square miles
kilometres	×	0.6215	=	miles
cubic decametres	×	1000	=	cubic metres
cubic metres	×	1000	=	litres

1.0 INTRODUCTION

1.1 Study Scope

This report provides an overview of the past and present streamflow volumes of nine major rivers in Alberta. Given recent drought conditions, comments about the status of water resources in the Province have been discussed in various forums. As well, questions have been raised about consumption patterns and the future sustainability of Alberta's water resources under the potential impacts of climate change. The study provides a context for understanding the current state of the resource, based on observed conditions covering a ninety-year period from 1912 to 2001. The selected rivers are affected by human activities and consumption to varying degrees. The intent of this study is to demonstrate at an overview level whether any significant long-term trends were notable. More subtle changes, such as in seasonal averages or changes in annual extreme events are beyond the scope of this report.

1.2 Study Area

Most of the major rivers in the Province are represented in the study and cover all of the major watersheds. Many of the rivers have more than one site where flow measurements have been taken over time. The locations chosen for the study were based primarily on the number of years of record available to maximize the data within the ninety-year timeframe. The longest possible data set provides a better indicator of conditions over the long-term. As well, preference was given to locations where annual streamflow volumes can essentially be considered natural or "mostly natural", although this was not possible in all cases. In those circumstances, naturalized flows were used. In the more highly impacted systems, natural flow data is calculated by taking recorded flow data and adjusting it to account for human impacts related to such activities as diversions, consumption, return flows, flow regulation by dams and reservoir evaporative losses. The selected rivers and gauging sites are shown in Figure 1.

Figure 1 Selected Major Rivers in Alberta with Study Locations.

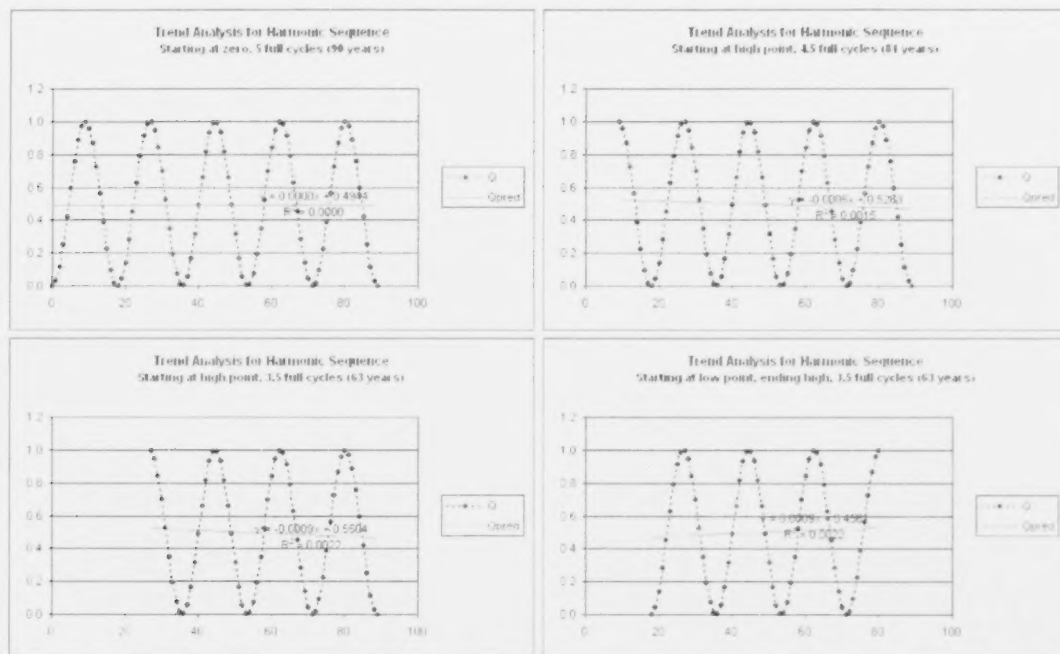


1.3 Trend Analysis Methodology and Rationale

Streamflow records were examined for potential trends using the non-parametric Mann-Kendall test (Helsel and Hirsch, 1992). A significance level of 95% was chosen as the criteria for determining if a trend was present. This means that if a trend is identified as significant (either positive or negative) that there is only a 5% (1 in 20) chance that the trend is actually not present. Conversely, it could also be said with 95% certainty that the trend is statistically significant. Kendall's tau (τ) uses a rank-based procedure to determine an estimate of correlation between two variables. In this study, the correlation between annual streamflow volume with time was calculated for each of the data sets. If a positive correlation or trend exists, then streamflow will tend to increase more often than decrease from year to year, while a negative correlation indicates that streamflow is tending to decrease more often over time. τ ranges in magnitude from +1 to -1. If no correlation is present (or $\tau \approx 0$) then annual streamflow will tend to increase and decrease about the same number of times from year to year. The τ from each data set is then subjected to a two-sided test to determine if the calculated sample τ is statistically different from zero, which would indicate the presence of a trend at the specified confidence level, in this case 95%.

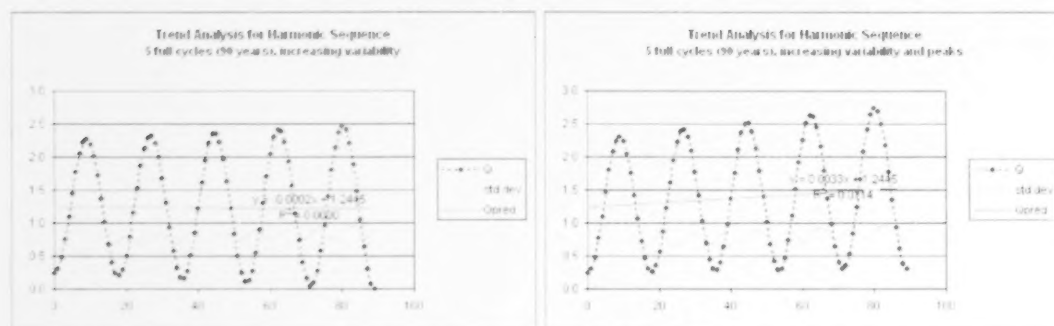
Using a non-parametric, rank-based trend analysis procedure is especially useful for data sets that are not normally distributed and may also contain data gaps, such as streamflow records. A simple linear trend line analysis approach was rejected as it is highly dependent on the start and end dates of a record and the relative position of those dates within a wet or dry climate cycle. This is illustrated by the set of simple harmonic data series below. The first image shows a fully cyclical pattern of five cycles over ninety values, with no slope on the trend line. The second image shows the same record but for 81 values (4.5 cycles) starting at a high point in the series and introducing a negative trending slope. The third and fourth images show a further shortening of the record to 3.5 cycles (63 values) for both high and low start dates, with a corresponding increase in the slope of the trend line. Variability (as indicated by the amplitude of the cycles) over time has been held constant.

Figure 2(a-d) Depiction of Simple Linear Trend Line Analysis Results using Simple Harmonic Sequence of Varying Lengths.



Although the Mann-Kendall test correctly produces both positive and negative τ 's for the short, 63-value records, the actual confidence in predicting whether the trend might be real is less than 40%, and is easily rejected as not significant. Further potential complications in trend analysis may arise when having to deal with changing variability over time, in addition to a potential underlying trend. Even if an overall trend is not identified, there may still be a pattern of increasing or decreasing variability in the streamflow, which would also be of interest. This concept is illustrated in the following two images; the first, showing no trend but increasing variability, and the second showing an increasing trend superimposed on an increasing trend in variability.

Figure 3(a-b) Depiction of Hypothetical Changes in Underlying Variability over Time using Simple Harmonic Sequences.



There is no statistical test for variability; however, it can be measured by the standard deviation of the underlying variable. In this case, a 15-year moving window of standard deviation, shown by the green line, was used to indicate the change in variability over time. In both cases, superimposed on the underlying ten year cycle is a general upward trend in the value of standard deviation, indicating an increase in variability.

2.0 HISTORIC STREAMFLOW VOLUMES

Whenever possible, recorded data that has been collected and published by the Water Survey of Canada (WSC) is the preferred data source. This was done so that any interpretation of streamflow data and the need for further extensive computations was minimized. However, rivers in the south are generally more highly impacted by diversions and therefore flow naturalization is required to provide a reasonable comparison to historic data and to other rivers. This was done for the Oldman, South Saskatchewan and Milk Rivers. In addition, four rivers are subject to flow regulation by one or more dams above the point of interest (Bow, North Saskatchewan, Peace, Red Deer). This has the effect of redistributing the flow pattern on a seasonal basis but annual flow volumes are essentially preserved. Recorded annual volumes were plotted in these cases. The two remaining rivers (Athabasca and Beaver) are considered essentially natural. Specific situations related to human impacts are described for each of the rivers in the individual sections.

Note that the individual plots of historical annual volumes for each of the rivers can be found in the Appendix, starting on page 23.

2.1 Athabasca River at Athabasca

Flow in the Athabasca River is considered to be natural. Total licensed consumption in the basin represents only a small fraction of the annual discharge in the river and there are no reservoirs on the Athabasca. The river originates in the Rocky Mountains at the Columbia Icefield in Jasper National Park. Flow is measured at five locations along the mainstem but the site at the Town of Athabasca has the longest period of record. Full year data is available for 1914 to 1930 and 1952 to 2001. In addition, data is also available for the May to October period in fourteen other years. Using linear regression, the annual (12 month) flow volume for those years was estimated based on the 6-month data. The drainage area at WSC station 07BE001 is 74,600 km² and the mean annual discharge is 423 m³/s.

The average annual runoff volume is about 13.3 billion m³, but has ranged from as high as 23.3 billion m³ in 1954 to an estimated low of 8.8 billion m³ in 1945. The upper Athabasca River basin upstream of Hinton is extremely productive, making up only 13% of the drainage area above the town of Athabasca but providing on average 40% of the flow volume. Recent highs in 1997 and lows in 2001 fit well within the observed range of variability. Other than alternating cycles of wetter and drier periods, there does not appear to be any long-term trend in the annual runoff yields.

2.2 Beaver River near Cold Lake Reserve

Available data for the Beaver River is not nearly as extensive as for the other rivers. However, based on the 46 years of recorded data from WSC station 06AD006, the mean annual discharge at this location is about 19.4 m³/s. This represents the period from 1956 to 2001. The contributing drainage area is 14,500 km² and flow is considered to be natural. Because of the shorter period of record, interpretation of averages and trends is more difficult. The recorded annual runoff volumes have ranged from 1.9 billion m³ in 1962 to 0.06 billion m³ in 1992. The average is about 0.61 billion m³.

This river is also unique from the others in the study in that it does not originate in the Rocky Mountains or foothills area of the Province. Therefore, it does not have the stabilizing influence of mountain snowpacks and is fed exclusively from plains or prairie runoff that is subject to greater variability. The range of flow between high and low years tends to be

higher and also the cycling between wet and dry periods appears to be more extended than for the other rivers. Because streamflow records in general for this part of the Province are relatively short, it is difficult to compare recent data to conditions that existed in the first half of this century. Based on the limited data available a significant negative trend was identified, although it is difficult to know if this is a statistical artifact of the shorter data set. Confirmation of long-term trend at this site is limited without the proper historical context.

2.3 Bow River at Calgary

At the City of Calgary and WSC gauge 05BH004, the Bow River drains an area of approximately 7,900 km². Based on a recorded annual data series of ninety years between 1912 and 2001, including estimated data for the period 1950 to 1953, the mean annual discharge is 91.1 m³/s. The recorded annual runoff volumes have ranged from 4.6 billion m³ in 1916 to 1.8 billion m³ in 1941. The average is approximately 2.9 billion m³.

Minor flow structures were in place as early as 1913 along the Bow River but the first significant structure, Ghost Reservoir, was completed in 1929. This was followed by the Glenmore, Lake Minnewanka, Upper Kananaskis, Barrier, Spray, Bearspaw and Lower Kananaskis reservoirs by 1955. Although there are now eight major reservoirs upstream of the Bow River at Calgary, the mean annual volumes recorded at the Calgary gauge are practically identical to the naturalized mean annual volumes that take into account changes in reservoir storage and reservoir net evaporative losses. Over the past 20 years, there is a less than a 4% difference, on average, between the natural and recorded data on an annual volume basis. Even so, this relatively minor consumption was enough to cause a significant negative trend to appear in the *recorded* flow data. However, a statistically significant trend was not identified in the naturalized flow data. This observation is confirmed by the long-term data from the Bow River at Banff. Although not specifically presented in this report, the Banff station is upstream of major human activity and is therefore a measure of natural streamflow. It also did not show a significant trend.

The water supply to the Bow River comes from both high precipitation amounts in the mountains with smaller quantities derived from the meltwater of glaciers in the Wapta and Waputik Icefields. On average 2.5% of the annual stream flow at the town of Banff is derived from glacier wastage (Young, 1996). During the summer months of July, August

and September this percentage can rise to between 4.6 and 7.5%. For years of very low annual runoff volume the annual contribution from the glacier can increase to between 5.2 and 16.8%, with August contributions ranging between 13.3 and 47.4%.

2.4 Milk River at Eastern Crossing of International Boundary

The Milk River is the sole major basin in Alberta that drains southwards to the Gulf of Mexico via the Missouri-Mississippi Rivers. The Milk River originates in the foothills of western Montana. Flowing northward, the Milk River enters southwestern Alberta (the western crossing of the International Boundary) then flows eastward through southern Alberta for about 250 km before re-entering eastern Montana (at the eastern crossing). The drainage area is about 6,500 km².

The Milk is also different from the other major rivers in that the Milk River is a net beneficiary of water diversions, which means that the recorded rivers flows are substantially higher (nearly double) than what would occur naturally. There is a major diversion from the St. Mary River into the Milk River using the U.S. St. Mary Canal. The diverted water enters the Milk River in the United States a few kilometres upstream of the western crossing of the international boundary and is conveyed across southern Alberta, via the Milk River, before re-entering the U.S. at the eastern crossing. Canada is not entitled to use the diverted water; rather, it is merely transported through Canada. The diversion is normally operated during the months of March to October, and its volume constitutes a significant portion of the flow recorded on the Milk River mainstem stations. The diversion has been in operation since about 1917.

Ninety years of recorded data are available at the Eastern Crossing gauge (WSC 11AA031). However, due to the St. Mary Diversion, this data requires naturalization before meaningful analyses can be completed. Naturalized flow data has been calculated and is available for the twelve-month annual period. For the recorded data, only open-water season (primarily 8 month) streamflow is available. The 12 month annual data for Eastern Crossing was estimated based on the 12 month flow data that is available from the WSC gauge at the town of Milk River (11AA005). The recorded mean annual discharge at Eastern Crossing is 9.88 m³/s or 0.31 billion m³. Recorded annual flow volumes have ranged from a high of 0.55 billion m³ in 1927 to 0.10 billion m³ in 1914. Natural flow volumes would have ranged

from a low of 0.02 billion m³ in 2001 to a high of 0.48 billion m³ in 1927. The long-term average annual natural flow is 0.16 billion m³ (5.07 m³/s).

The majority of the Milk River basin (within Canada) lies in semi-arid prairies. Because of the dry climate, there are great demands on the limited water resources in the region. As such, the Milk River is a critical source of water for agriculture and municipal use. The large U.S. diversions mean that there is a significant positive trend in recorded streamflow, however once these effects were removed no long-term trend was identifiable.

2.5 North Saskatchewan River at Edmonton

The North Saskatchewan River at Edmonton is one of the few rivers in the Province with a consistent and uninterrupted data record. Recorded 12 month data is available for the entire ninety-year period of study. Two dams, Bighorn and Brazeau, have impacted the natural streamflow through regulation since 1960 and 1973, respectively. The recorded annual runoff volumes due to regulation are considered to be fairly close to natural as only the timing of flows has been altered. Mean annual discharge at Edmonton is 212 m³/s with a drainage area of 28,000 km². Annual flow volumes have ranged from a high of 11.5 billion m³ in 1954 to 4.4 billion m³ in 1975. The long-term average is 6.7 billion m³.

There are some relatively significant water allocations upstream and in the vicinity of the City of Edmonton gauging station, including several coal-fired power plants and the municipal water supply for the city. The total allocations can be misleading because the actual amount of water that is consumed is generally below the licensed limits and, depending on the usage, often a large percentage of the withdrawals are eventually returned back to the river. For example, Edmonton returns the majority of its allocation downstream of the WSC gauge, meaning that the recorded flow at Edmonton would be less than what is actually available because the WSC gauge does not capture the return flows. As the withdrawals have tended to increase over time, the reduction in recorded streamflows (as compared to historic values) has also increased. The cumulative consumption upstream of the Edmonton gauge 05DF001 is estimated to be less than 5% of recorded annual discharge. This is of a similar relative magnitude as for the Bow River at Calgary. A significant negative trend (at 95%) was identified in the recorded data for the North Saskatchewan River at Edmonton. However, as was the case for the Bow at Calgary, it is possible that if the North

Saskatchewan data set were fully naturalized, the effects of consumption would be removed and the negative trend would no longer be significant. This must still be confirmed.

2.6 Oldman River near Lethbridge

Approximately ninety years of data have been collected at WSC gauge 05AD007, Oldman River near Lethbridge, beginning in 1912. The recorded mean annual discharge at Lethbridge is $81.8 \text{ m}^3/\text{s}$ with a drainage area of $17,000 \text{ km}^2$. Recorded annual flow volumes have ranged from a high of 6.1 billion m^3 in 1927 to 0.53 billion m^3 in 1977. The long-term average is 2.6 billion m^3 .

Even before the recording period at the Lethbridge gauge began, the St. Mary Irrigation District was diverting water from the Oldman River system for the purposes of irrigation. Within the next twenty years the Lethbridge Northern, United, Mountain View, Leavitt and Aetna Irrigation Districts were added to the irrigation infrastructure in the Oldman River basin. In addition to the effects of the irrigation district operations, the construction of the St. Mary Reservoir in 1951, Waterton Reservoir in 1965, Chain Lakes Reservoir in 1966 and Oldman Reservoir in 1991 have resulted in seasonal changes in the Oldman River flow regime as well as an increase in the water lost through reservoir surface water evaporation. To determine the total amount of available flow in the basin the recorded data series must be naturalized. This was accomplished by accounting for reservoir changes in storage, reservoir net evaporative losses, river channel routing, City of Lethbridge net consumption as well as irrigation diversions, irrigation returns and U.S. diversions to the Milk River.

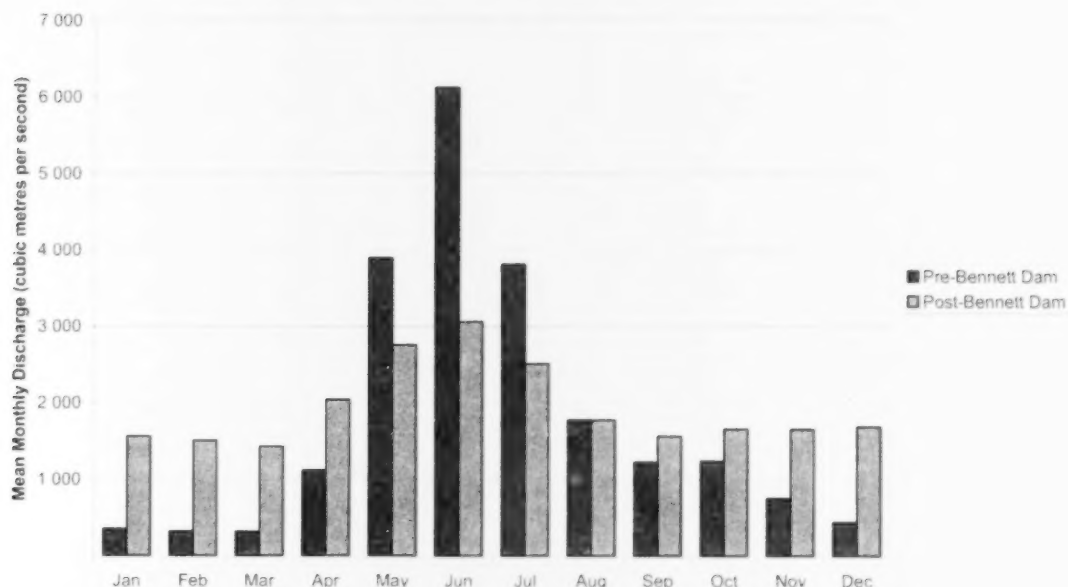
The naturalized mean annual discharge at Lethbridge is $109 \text{ m}^3/\text{s}$. Naturalized annual flow volumes range from as high as 7.0 billion m^3 in 1951 to 1.4 billion m^3 in 1944. The long-term average is 3.5 billion m^3 . The naturalized data series does not show any long-term trends aside from the expected wet and dry cycles. The recorded data series does show a decrease in the annual flow volume over time compared to the naturalized series. This can be attributed to the increased consumption and water infrastructure operations upstream of Lethbridge. Net consumption in the Oldman upstream of Lethbridge has grown from an annual average of 0.34 billion m^3 during the 1920's to about 1.4 billion m^3 per year during the 1990's.

2.7 Peace River at Peace River

Historically, the Peace River originated at the confluence of the Finlay and Parsnip Rivers in northeastern British Columbia. However, since the construction of W.A.C. Bennett Dam (and later, the Peace Canyon Dam) by B.C. Hydro, the Peace River now begins as the outflow from Williston Reservoir, located about 170 km upstream of the Alberta-British Columbia border. The river's contributing drainage area at the Town of Peace River is about 194,000 km² and the recorded mean annual discharge is 1830 m³/s. The available period of record is 1916 to 1930 and 1958 to 2001. Filling of Williston Reservoir took place over the years 1968 to 1971 and the river has been regulated by B.C. Hydro operations since 1972.

The purpose of the Bennett Dam is to produce hydroelectric power, which requires relatively stable discharge for optimal production. Therefore, water is held back during the spring and summer peak flows and more water is released during winter months. At the Town of Peace River, the flow would naturally fluctuate from late winter lows of about 320 m³/s to over 6000 m³/s in June. Since the construction of the Bennett Dam, these seasonal extremes have been reduced as shown in Figure 4. This may be one reason for the perception that streamflow in the Peace River has declined over time, when in fact the streamflow has only been redistributed over the year. The overall amount of water in the Peace River has not changed due to either regulation or other anthropogenic activities although a positive trend in annual streamflow was identified at 95% significance. There is a large data gap in the early to middle part of the century. Both 1996 and 1997 were relatively wet years throughout Northern Alberta, but the record flow in 1996 on the Peace (91.0 billion m³) was also due to the partial drawdown of the reservoir to facilitate repair of a sinkhole. The reservoir returned to normal operating conditions in 1997, which was also a high runoff year for the river despite the re-filling of Williston Reservoir. The lowest year occurred during the first year of reservoir filling in 1968, with a runoff volume of 29.1 billion m³. The long-term average is 57.7 billion m³.

Figure 4 Change in Mean Monthly Discharge for the Peace River at Peace River due to Regulation by W.A.C. Bennett Dam



2.8 Red Deer River at Red Deer

The WSC gauge 05CC002 – Red Deer River at Red Deer has, excluding the beginning of 1912 and sporadic periods between 1931 and 1935, a continuous data set going back to 1913. The recorded mean annual discharge at the City of Red Deer is 47.5 m³/s with a contributing drainage area of 11,600 km². Recorded annual flow volumes have ranged from a high of 4.0 billion m³ in 1954 to 0.66 billion m³ in 1984. The long-term average is 1.5 billion m³.

Beginning in 1983 the flow of the Red Deer River has been influenced by the operations of the Dickson Dam, which is located 40 kilometers southwest of the City of Red Deer and 35 kilometers northeast of the Town of Sundre in southwestern Alberta. Overall, the impacts on the annual volumes related to the dam operation and from other licensed uses are negligible and the recorded annual flows are considered to be near natural. Other than the variation expected from climatic cycles, no significant long-term trend was identified.

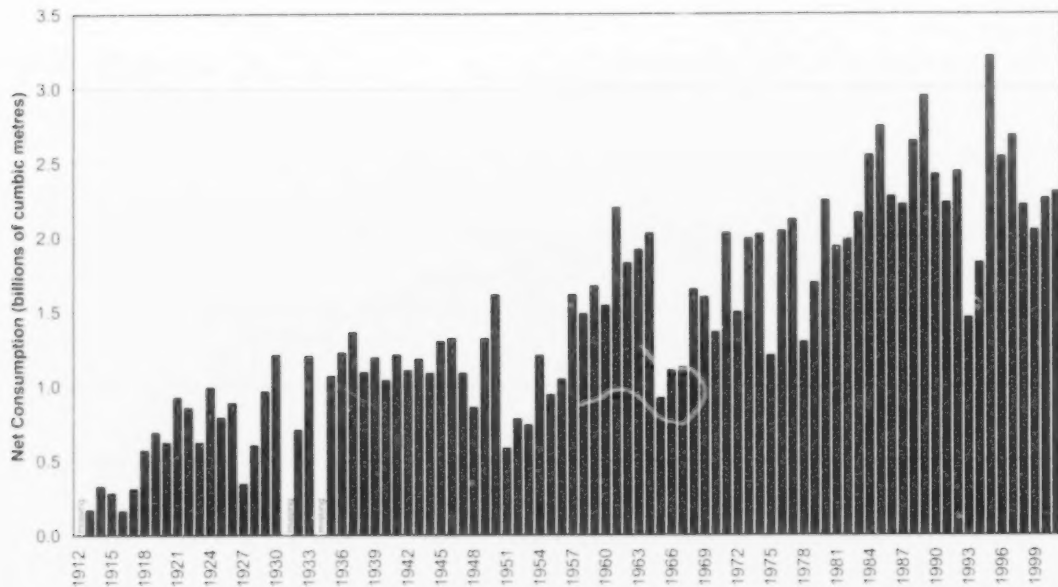
2.9 South Saskatchewan River at Medicine Hat

Systematic streamflow records are available for the South Saskatchewan River at Medicine Hat, WSC gauge 05AJ001, since 1912, excluding a period of five years in the early thirties when periods of sporadic data collection occurred. The recorded mean annual discharge at Medicine Hat is $190 \text{ m}^3/\text{s}$ with a drainage area of $56,400 \text{ km}^2$. Recorded annual flow volumes have ranged from a high of 13.2 billion m^3 in 1951 to a low of 1.7 billion m^3 in 2001. The long-term average is 6.0 billion m^3 .

The South Saskatchewan River basin has undergone considerable change since the start of the recording period. The impacts of urbanization, regulation and agricultural irrigation have all gradually but significantly increased in magnitude over the last nine decades. In order to account for the effects of reservoir storage, irrigation and municipal water use on the flow within the system, flows at Medicine Hat have been naturalized. The difference between the recorded discharge and the natural discharge represents the consumptive use of large municipalities and agricultural irrigation. The naturalized mean annual discharge at Medicine Hat is $234 \text{ m}^3/\text{s}$. Naturalized annual flow volumes range from as high as 13.8 billion m^3 in 1951 to a low of 3.7 billion m^3 in 1944. The long-term average is 7.4 billion m^3 .

The naturalized data series does not show any long-term trends aside from the expected wet and dry periods. The recorded data series does show a decrease in the annual flow volume over time, which when compared to the naturalized data series, can be attributed to the increased water demands and consumptive use that has occurred in the South Saskatchewan River basin. Over time, net consumption in the South Saskatchewan River upstream of Medicine Hat has grown from an annual average 0.76 billion m^3 in the 1920's to 2.3 billion m^3 during the 1990's. Refer to Figure 5 showing the estimated annual net consumption upstream of Medicine Hat, calculated by subtracting the recorded annual volumes from the annual naturalized flow volumes.

Figure 5 Estimated Annual Net Consumption in the South Saskatchewan River upstream of Medicine Hat, 1912-2001.



2.10 Summary

Based on the Mann-Kendall test of the annual streamflow data, the majority of the rivers do not exhibit a significant trend at the 95% level of significance. However, even though the significance criterion was not triggered in most cases, the tau-statistic was still negative in six out of the nine data sets. This may indicate that if drier than average conditions continue to persist, that a trend may become more established. At present, there does not appear to be sufficient information to indicate a clear break from historical patterns.

Table 1 **Summary of Streamflow Trend Analysis Results.**

River	Range of Data (number of years)	tau-statistic	Trend? (95% significance)
Athabasca <i>at Athabasca</i>	1913-30; 1938-40; 1942-2001 (81)	Mildly Positive	Non-Detect
Beaver <i>near Cold Lake Reserve</i>	1956-2001 (46)	Strongly Negative	Significant
Bow <i>at Calgary</i> (Natural Flows)	1912-2001 (90)	Negative	Not Significant
Milk <i>at Eastern Crossing of International Boundary</i> (Natural Flows)	1912-2001 (90)	Mildly Negative	Non-Detect
North Saskatchewan <i>at Edmonton</i>	1912-2001 (90)	Strongly Negative	Significant (?) ¹
Oldman <i>near Lethbridge</i> (Natural Flows)	1912-2001 (90)	Mildly Negative	Non-Detect
Peace <i>at Peace River</i>	1916-31; 1958-2001 (60)	Strongly Positive	Significant
Red Deer <i>at Red Deer</i>	1912-2001 (90)	Negative	Not Significant
South Saskatchewan <i>at Medicine Hat</i> (Natural Flows)	1912-2001 (90)	Negative	Not Significant

¹ Trend line may be affected by net consumption (natural flow data set not available).

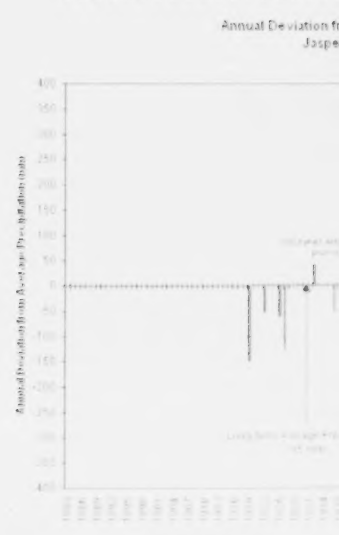
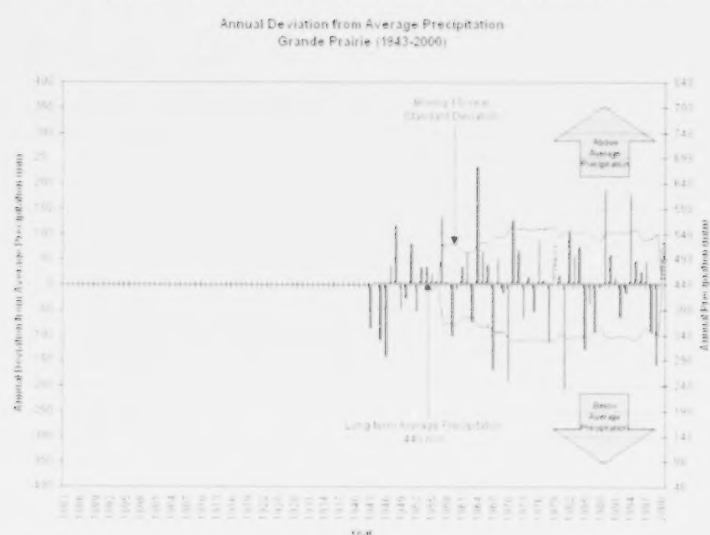
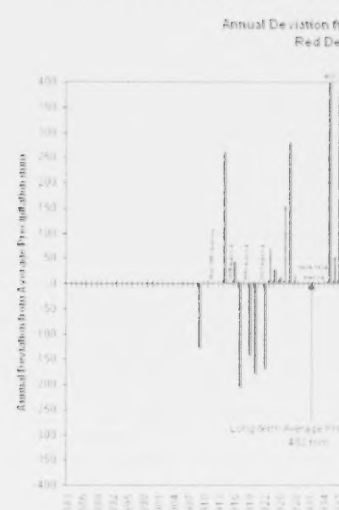
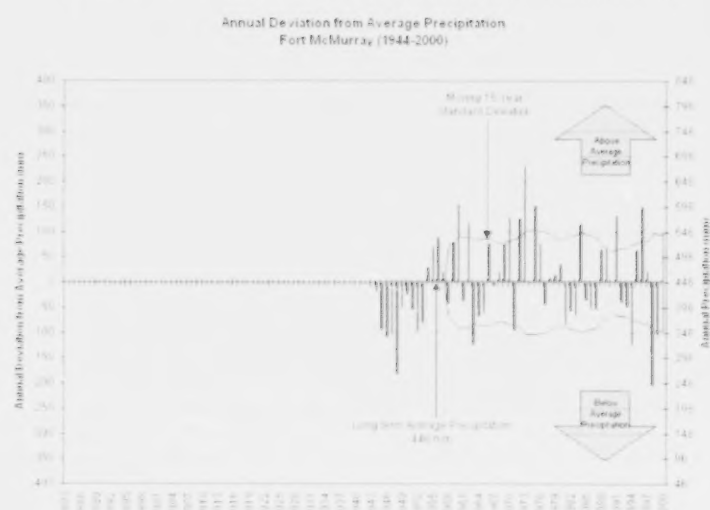
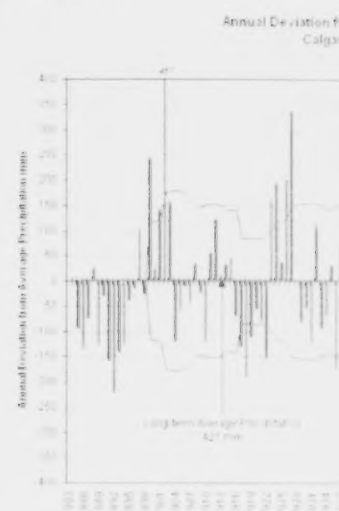
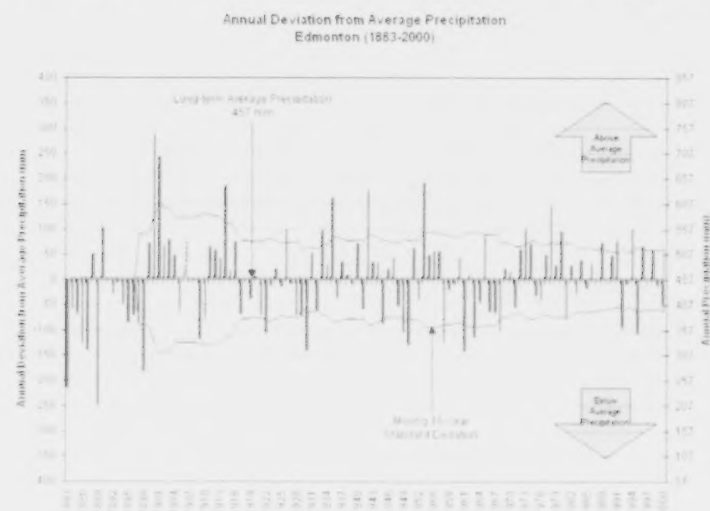
3.0 PRECIPITATION

Variability in annual streamflow volumes is significant within the long-term records. This suggests that detection of meaningful trends could easily be masked by both natural variability and the relative shortness of some of the records, which may not reflect the potential presence of longer-term climatic cycles. As precipitation is one of the key drivers of runoff and streamflow, examining recorded precipitation may also provide insight into whether a deviation in the historically observed climate patterns may be occurring. The main benefit of using precipitation is that it tends to be less variable than streamflow. Precipitation tends to vary (typically) within $\pm 100\%$ of the mean, whereas streamflow can often vary over an order of magnitude or more. However, one of the drawbacks is that precipitation represents a point value and cannot necessarily be expanded to present a depiction of an entire watershed. There are also a limited number of stations in the Province where long-term, continuous precipitation data has been collected. Nine locations in Alberta have been assessed for long-term precipitation data, ranging from 56 to 117 years of record.

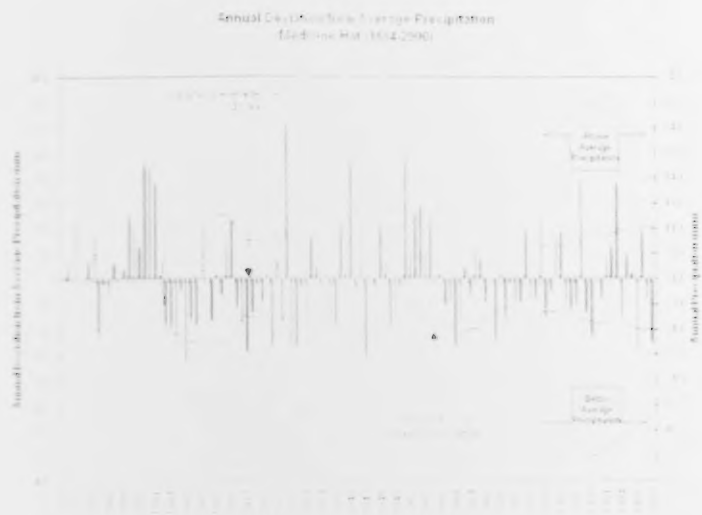
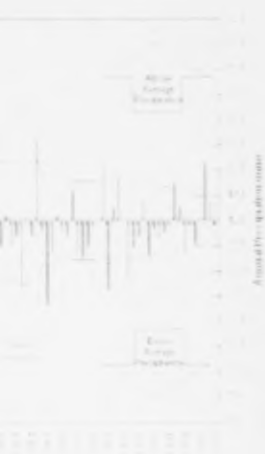
3.1 Deviation from Average Precipitation

Plots of the annual deviation from the long-term average precipitation were selected in order to illustrate the historical precipitation data. This approach shows how each of the years of data compares to the overall average. The horizontal red line represents the average of all available years and plots as a zero deviation on the left axis. For ease of reference, the right axis shows the corresponding annual precipitation total. Bars that plot above the red line are years that are above average, while those plotting below are below the average. Superimposed on the chart is the moving 15-year standard deviation, shown as a yellow area, which is a measure of the variability over time. The further the yellow area is from the central red axis, the greater the variability in the preceding 15-year period. All precipitation sites are plotted in Figure 6.

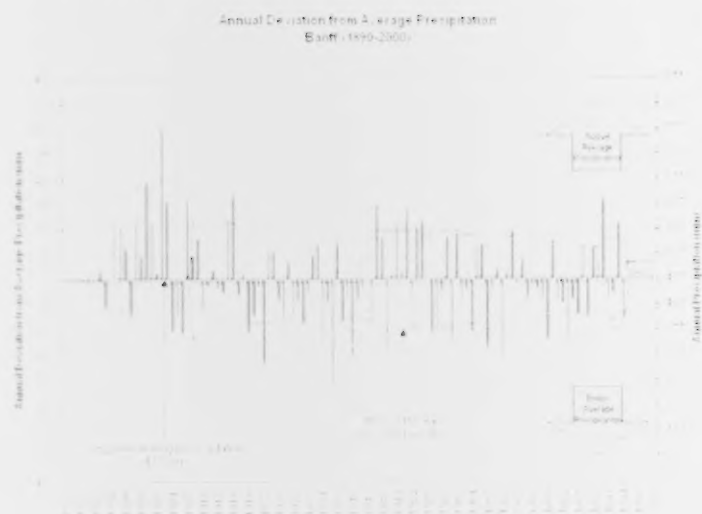
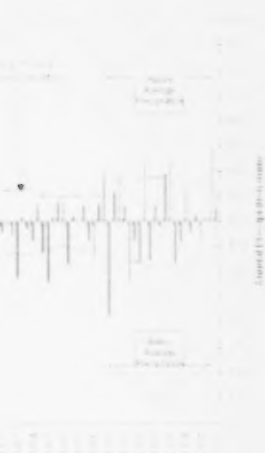
Figure 6(a-i) Plots of Annual Deviations from Long-Term Average Precipitation



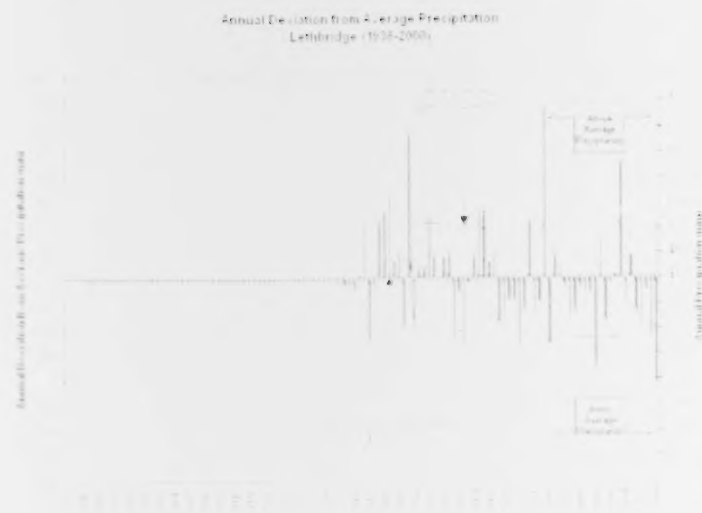
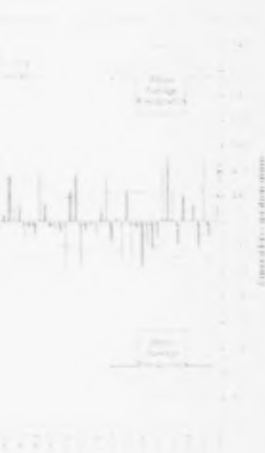
precipitation



precipitation



precipitation



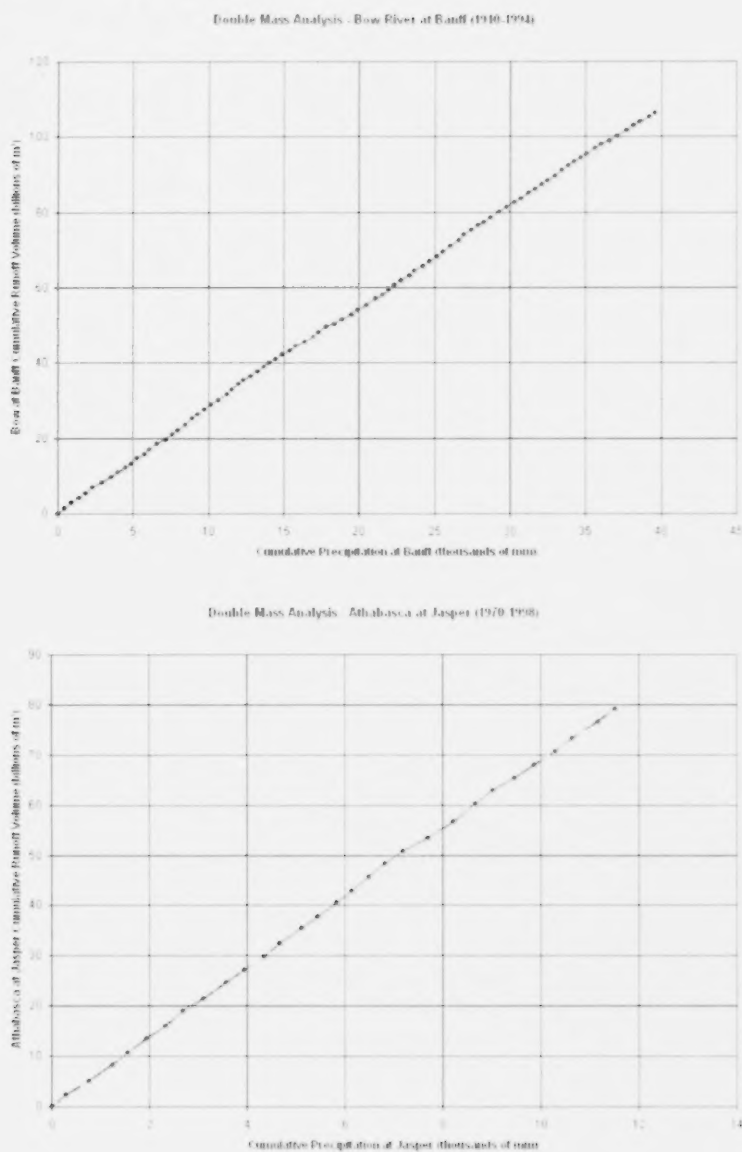
Examining the plots seems to indicate a general pattern of decreasing variability at many of the sites. This phenomenon is especially noticeable at Calgary, Red Deer and Edmonton, and to a lesser extent at Banff, Medicine Hat and Jasper. By coincidence, these stations also have the longest periods of record. This suggests that relatively short hydrometeorological data of less than 50 to 60 years may not be adequate for Alberta in order to fully capture long-term cycles or trends in climate data. While the variability may be decreasing at some locations, overall there is a slight positive trend in annual precipitation at the nine stations examined. Three stations exhibited no real trend, while four of the sites displayed trends that were not statistically significant (three were positive and one negative). One station (Edmonton) exhibited a significant positive trend (at 95%) while another (Lethbridge) exhibited a significant negative trend.

3.2 Double Mass Curves

Climate change predictions obtained from Global Circulation Models (GCM's) appear to indicate a potential "acceleration" of the hydrologic cycle in Alberta, meaning that increased temperatures would lead to increased precipitation and further to increased evaporation and transpiration. Whether or not runoff and streamflows would decrease would depend upon if the increased evapotranspiration would exceed any increases in annual precipitation. However, given that precipitation forms the major input to streamflow generation, the ability to relate these two variables could provide additional information on whether or not a change may be occurring. A double mass curve is an analytical tool where the cumulative precipitation and cumulative runoff are plotted on the same graph against one another. If the relationship is relatively stable, the slope of the line will be fairly linear and remain approximately constant. However, if a change in precipitation, runoff, or both, were to occur, the slope of the line would deviate from the historical pattern.

This second type of analysis was performed at two of the precipitation stations where it was reasonable to assume that the long-term pattern of accumulated precipitation could be linked to the long-term pattern of accumulated streamflow. Comparison of total precipitation to total runoff at Jasper (Athabasca River) and Banff (Bow River) was used. The catchments for these rivers are relatively small at these headwater locations and the precipitation gauges could reasonably approximate a basin-average pattern of precipitation. These are shown in Figure 7.

Figure 7(a-b) Double Mass Analysis Curves for Banff (Bow River) and Jasper (Athabasca River).



Both figures show a relatively constant slope (blue being the recorded, pink being 100% linear). A feature of this type of analysis is that because of the coupling of precipitation and runoff, any change in one or the other (or both) would result in a change in the slope of the accumulation line. Such a marked deviation from historical patterns is not immediately evident.

4.0 SUMMARY

Historical annual streamflow volumes have been summarized for nine major rivers throughout Alberta over a ninety year period spanning the years 1912 to 2001. The intent was to determine if a significant long-term trend in river flows could be observed. In most cases a summary of the recorded streamflow volumes, provided by Water Survey of Canada, was sufficient to illustrate the long-term data where human impacts were found to have minor or negligible effects on the computation of the volumes on an annual basis. For three rivers in southern Alberta it was necessary to rely on computed natural streamflow in addition to the recorded data sets as changes due to human activities are much more pronounced. Comparisons of natural or naturalized flows amongst the nine rivers provides a common frame of reference and also allows any changes that may be observed over time to be understood and to attributed to the correct source.

Once the effects of regulation, licensed consumption and diversions are either removed from the data sets or put in the proper context, it appears that the underlying patterns of natural runoff and climate do not appear to have changed significantly over the past ninety years. Using the Mann-Kendall rank-based correlation and trend analysis procedure, three potential statistically significant trends (at a 95% confidence level) were identified – two negative and one positive. Of potential concern is that, although not necessarily found to be significant, the directional tendency at many of the stations was negative. Some questions remain as to whether the identified negative trends for the Beaver River (much shorter data record, different topographic origin) and North Saskatchewan River (affected by net consumption?), and the positive trend for the Peace River (mid-century data gap) are conclusive. In general, on an annual basis the patterns of wetter and drier cycles continue to appear in all of the records and when recent extremes have occurred (either highs or lows), they do not appear to be outside the range of observed variability. It is likely that the perception of change is driven by humans impacting the timing of flows through flow regulation and by the various diversions and net consumption in the south that has altered the recorded flow patterns over time.

Annual precipitation exhibited no strong directional trend, although the tendency was toward increasing annual precipitation. Variability in annual precipitation totals seems to be decreasing. The seeming contradiction between negative-trending streamflow and positive-

tending precipitation might be explained by taking a closer look at seasonal patterns in precipitation. Increased summer precipitation may be offsetting the smaller prairie snow packs that are so often noted during drought periods. It is known that snowmelt runoff tends to be one of the most productive contributors to streamflow, as it occurs while the ground is frozen or saturated. Summer rainfall events, though capable of producing large storms, can often contribute proportionally less as the rainfall is infiltrated into the soil or captured in depressional storage. Another potential explanation for a reduction in streamflow, despite stable or increasing precipitation, might be increased evaporation and evapotranspiration. These hypotheses have yet to be tested.

While at this time definitive change has not been observed, continued monitoring can provide further confirmation or identification of trends should they emerge in the future. Further studies examining whether seasonal changes in natural streamflow and precipitation patterns may be occurring could also be valuable.

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Alberta Environment, *South Saskatchewan River Basin Historical Weekly Natural Flows 1912-2001*, Environmental Monitoring and Evaluation Branch, Edmonton, 2003.

Helsel, D.R., and R.M. Hirsch, *Statistical Methods in Water Resources*, Elsevier Science Publishers, Amsterdam, 1992.

Water Survey of Canada, *HYDAT CD of Canadian Hydrological Data (Version 2.01)*, Environment Canada, 2001.

Young, G.J., *An identification of the contribution (quantity and timing) of release water from long-term storage as glacier ice to the flow of the Bow River at Banff and to its sub-basins: Phase I (b): Contribution of Glacial Melt Water to the Flow of the Bow River*, Wilfrid Laurier University, 1996.

APPENDIX: STREAMFLOW PLOTS

Athabasca River at Athabasca

Beaver River near Cold Lake Reserve

Bow River at Calgary

Milk River at Eastern Crossing of International Boundary – Naturalized and Recorded Data

North Saskatchewan River at Edmonton

Oldman River near Lethbridge – Naturalized and Recorded Data

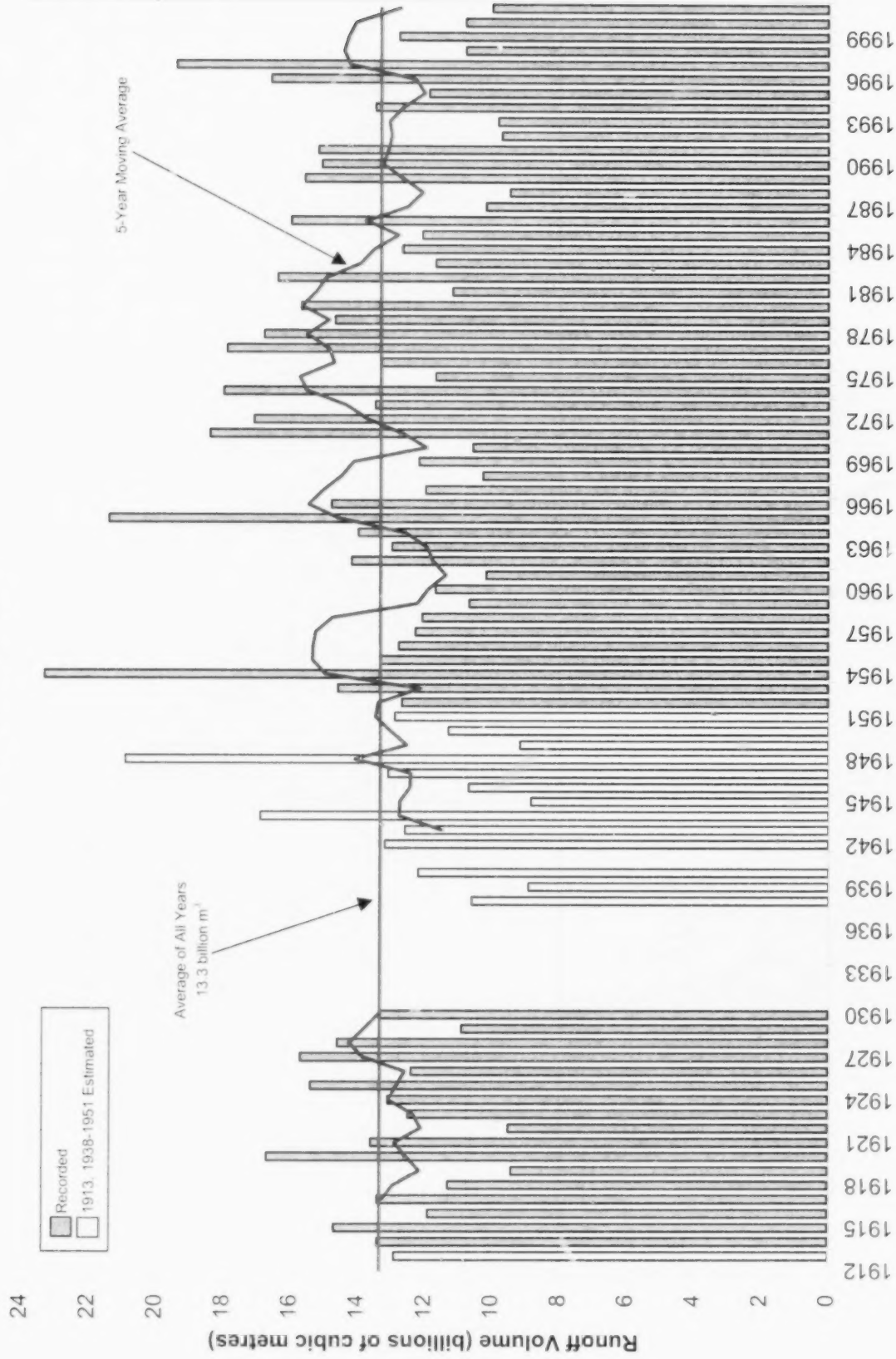
Peace River at Peace River

Red Deer River at Red Deer

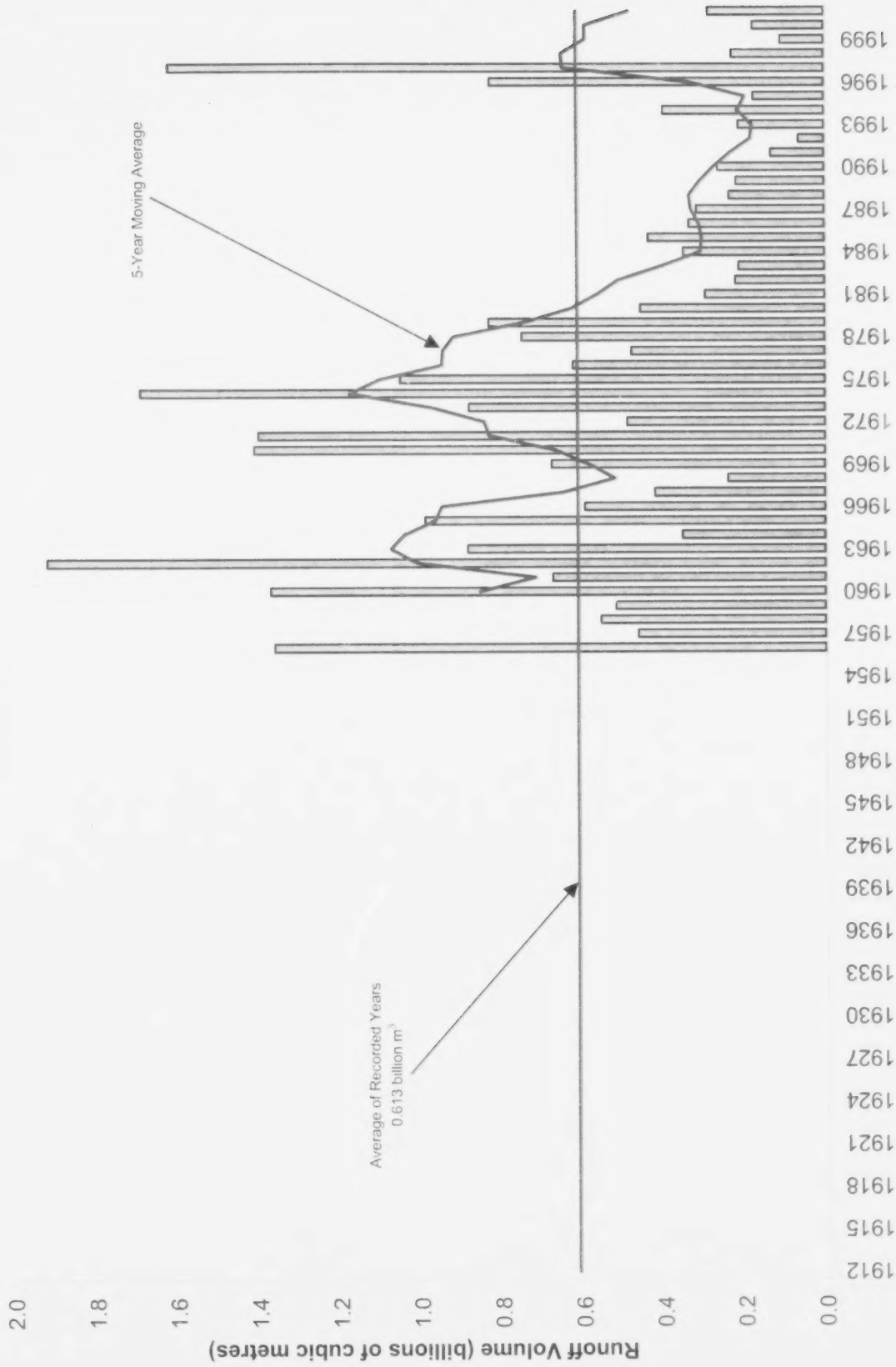
South Saskatchewan River at Medicine Hat – Naturalized and Recorded Data

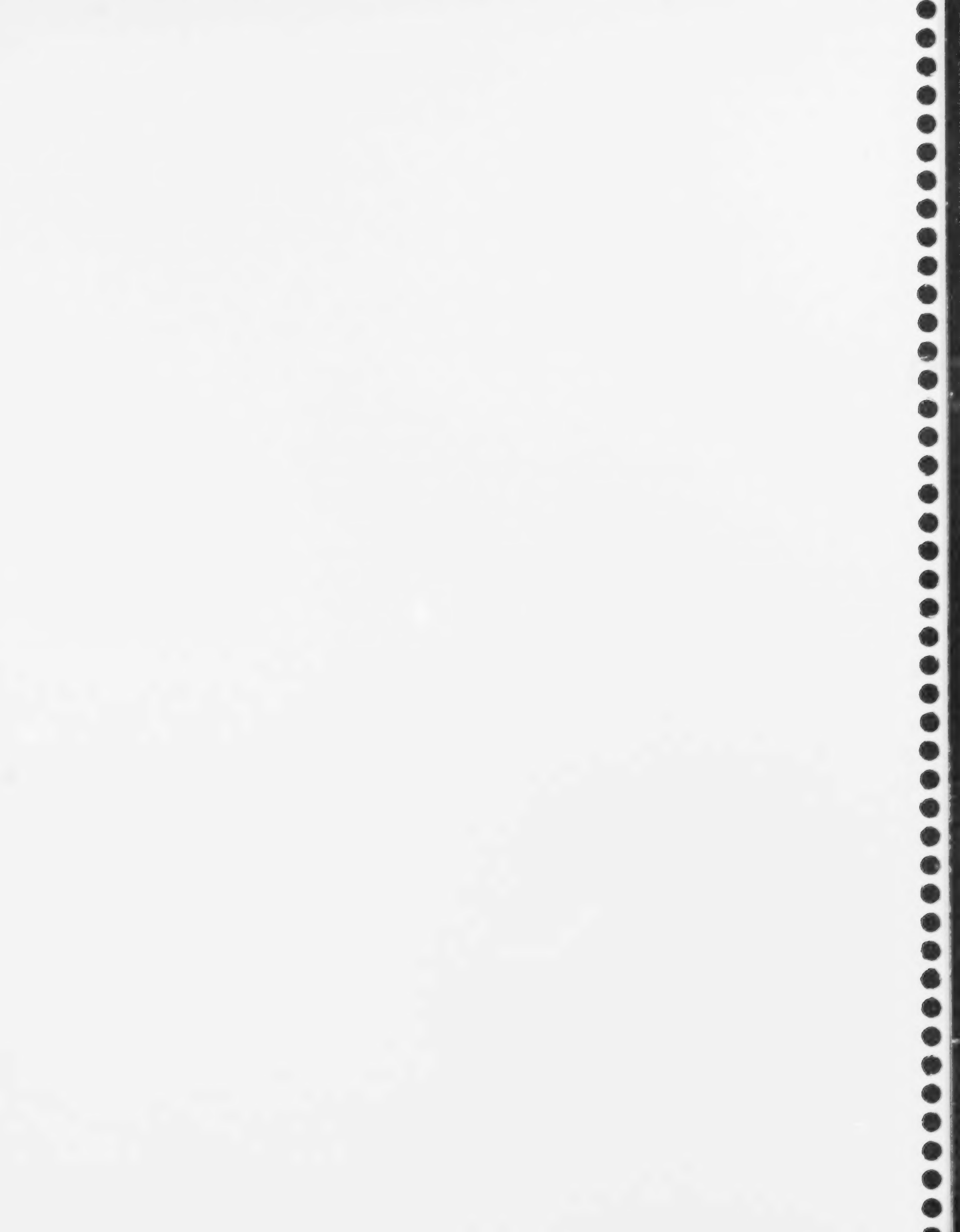
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Recorded Annual Runoff Volume for the Athabasca River at Athabasca (WSC # 07BE001)

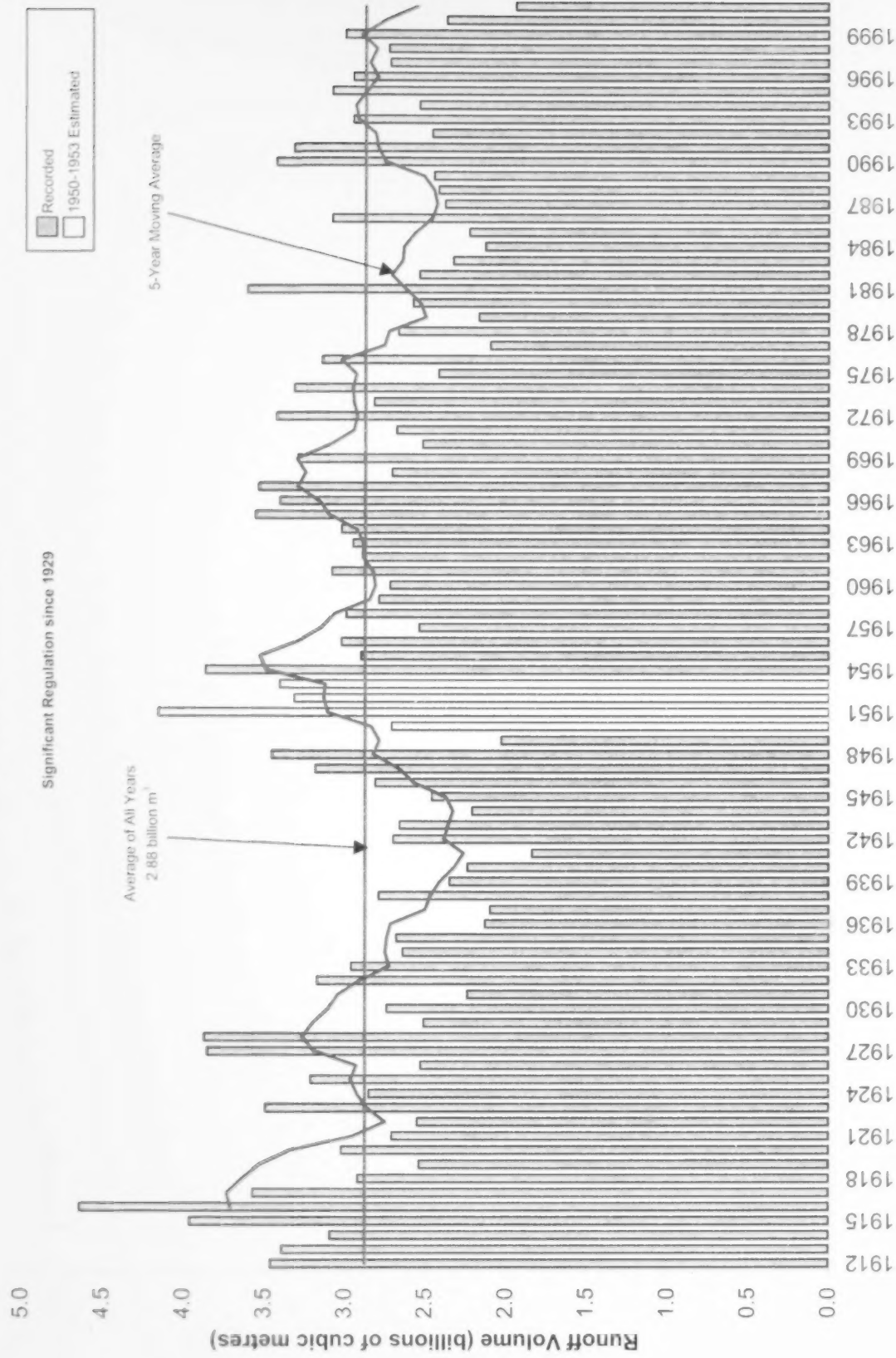


Recorded Annual Runoff Volume for the Beaver River near Cold Lake Reserve (WSC # 06AD0006)

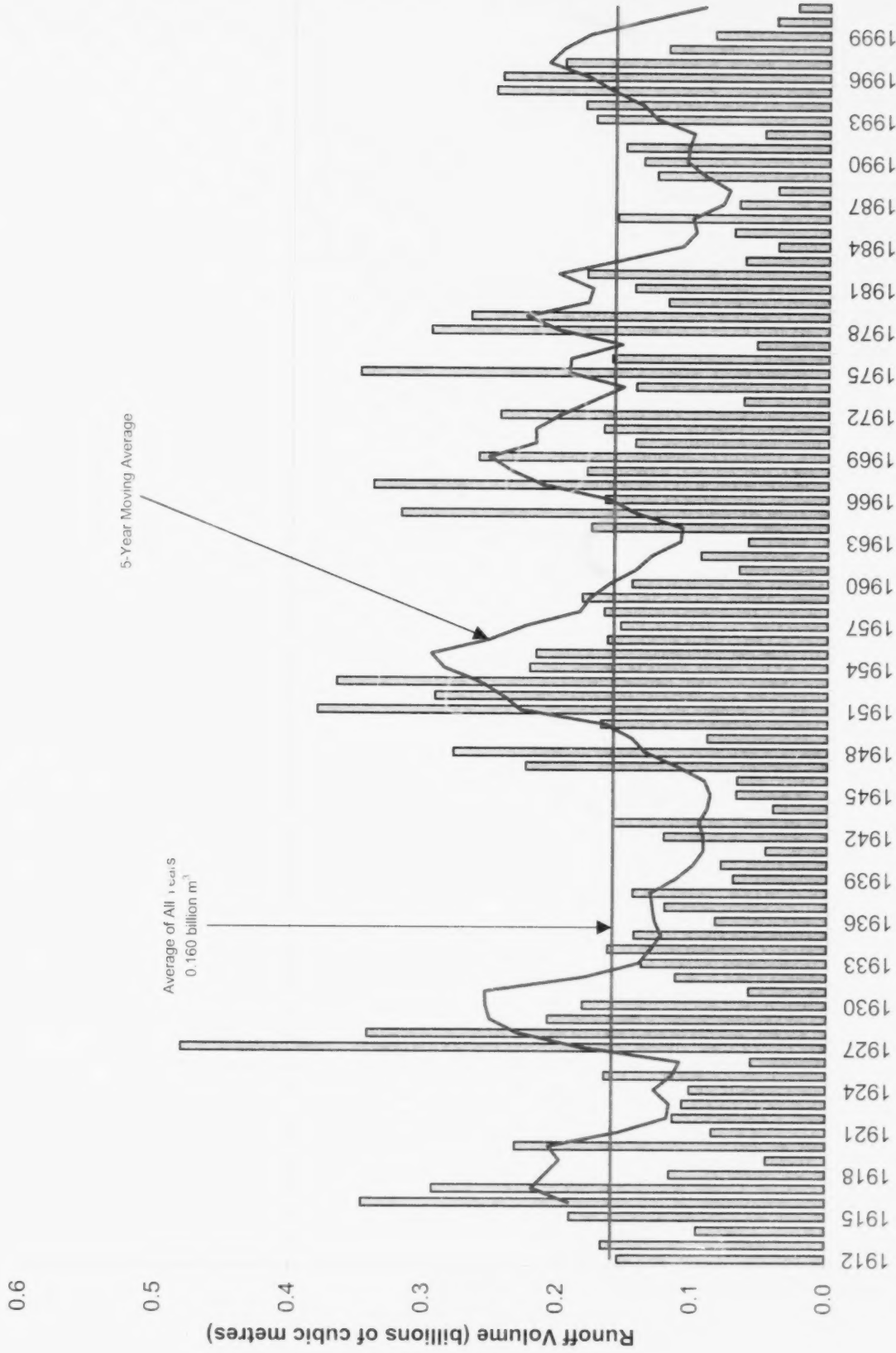




Recorded Annual Runoff Volume for the Bow River at Calgary (WSC # 05BH004)

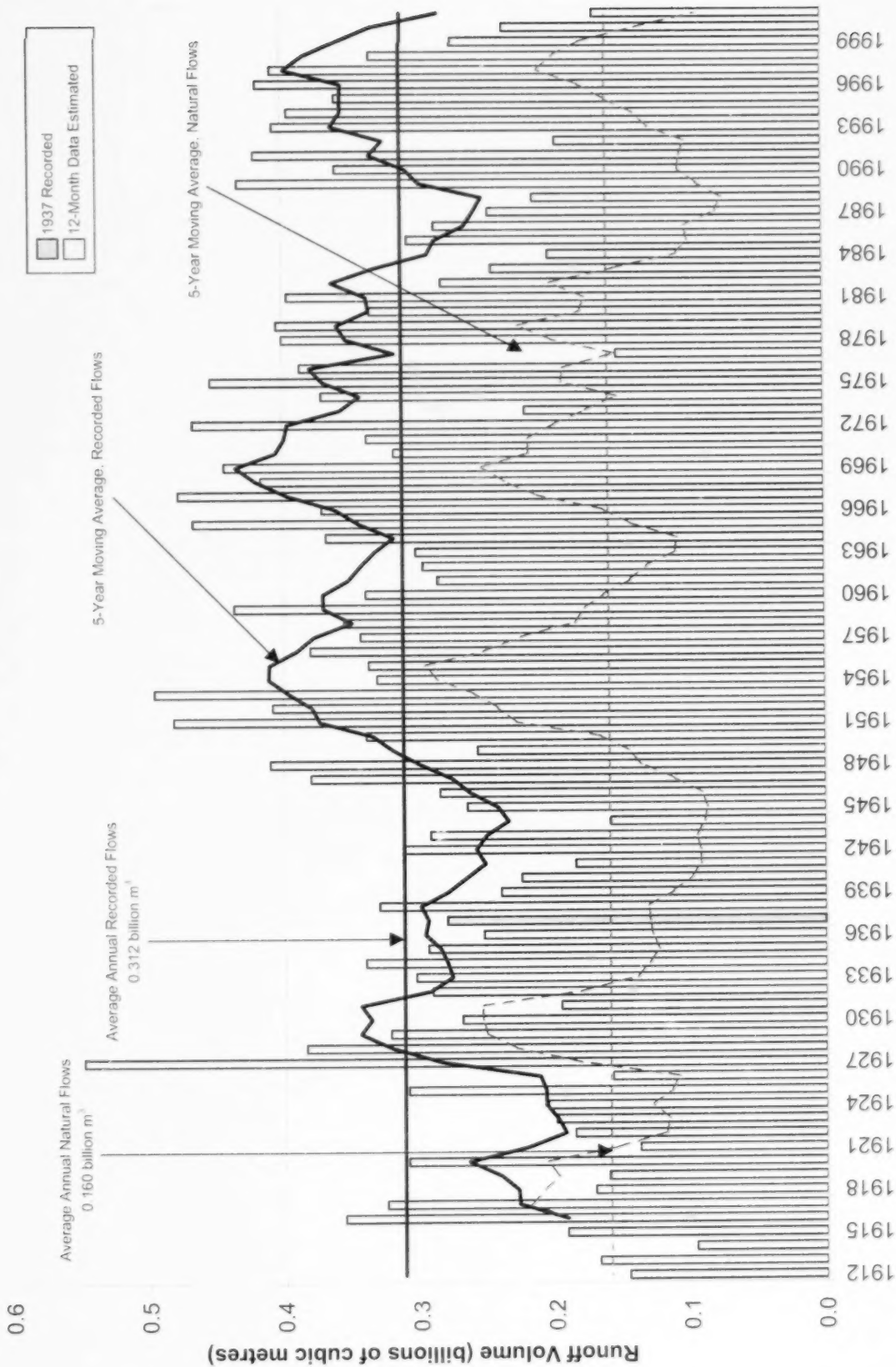


Naturalized Annual Runoff Volume for the Milk River at Eastern Crossing of International Boundary

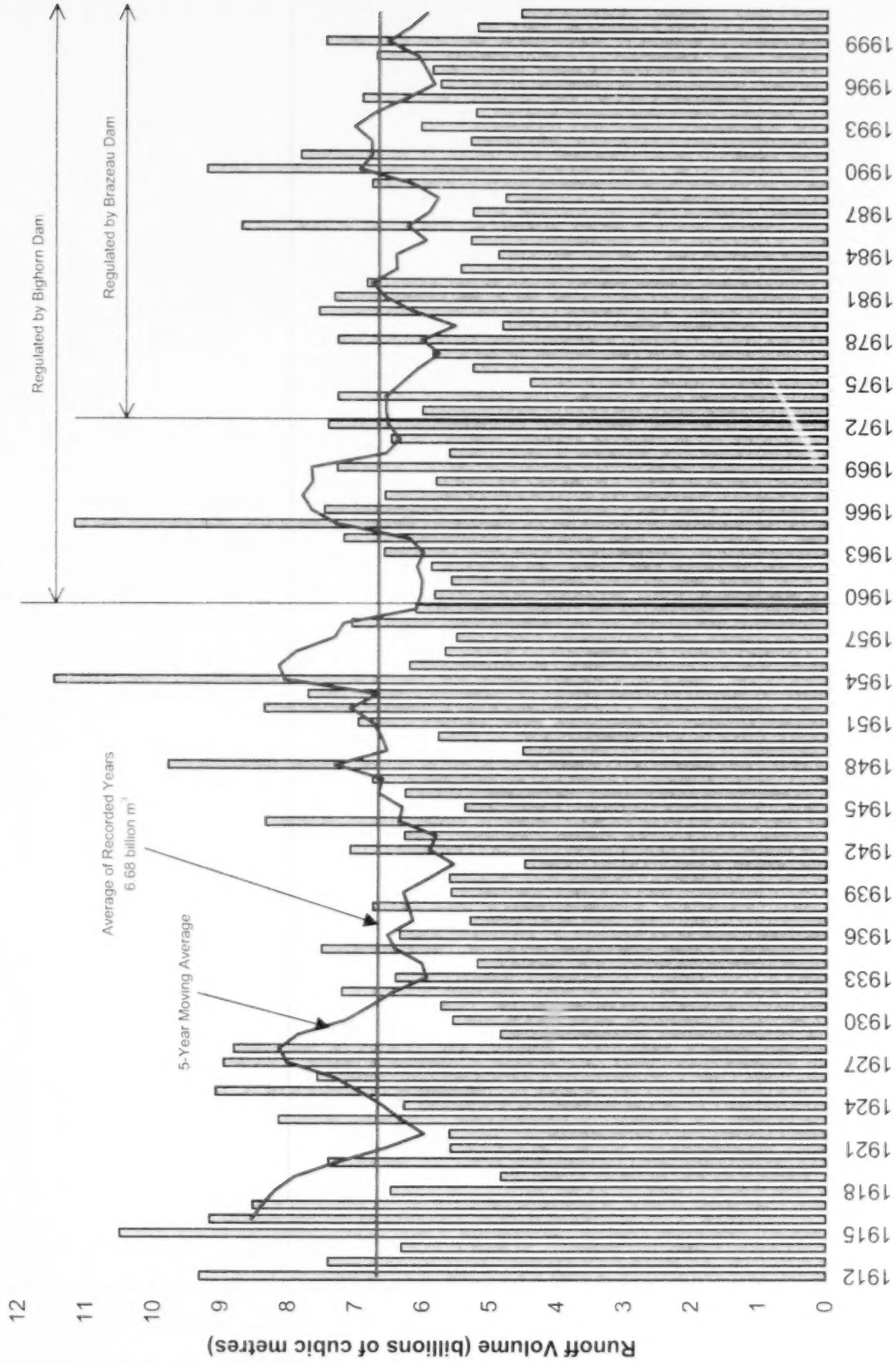




Recorded Annual Runoff Volume for the Milk River at Eastern Crossing of International Boundary (WSC # 11AA031)

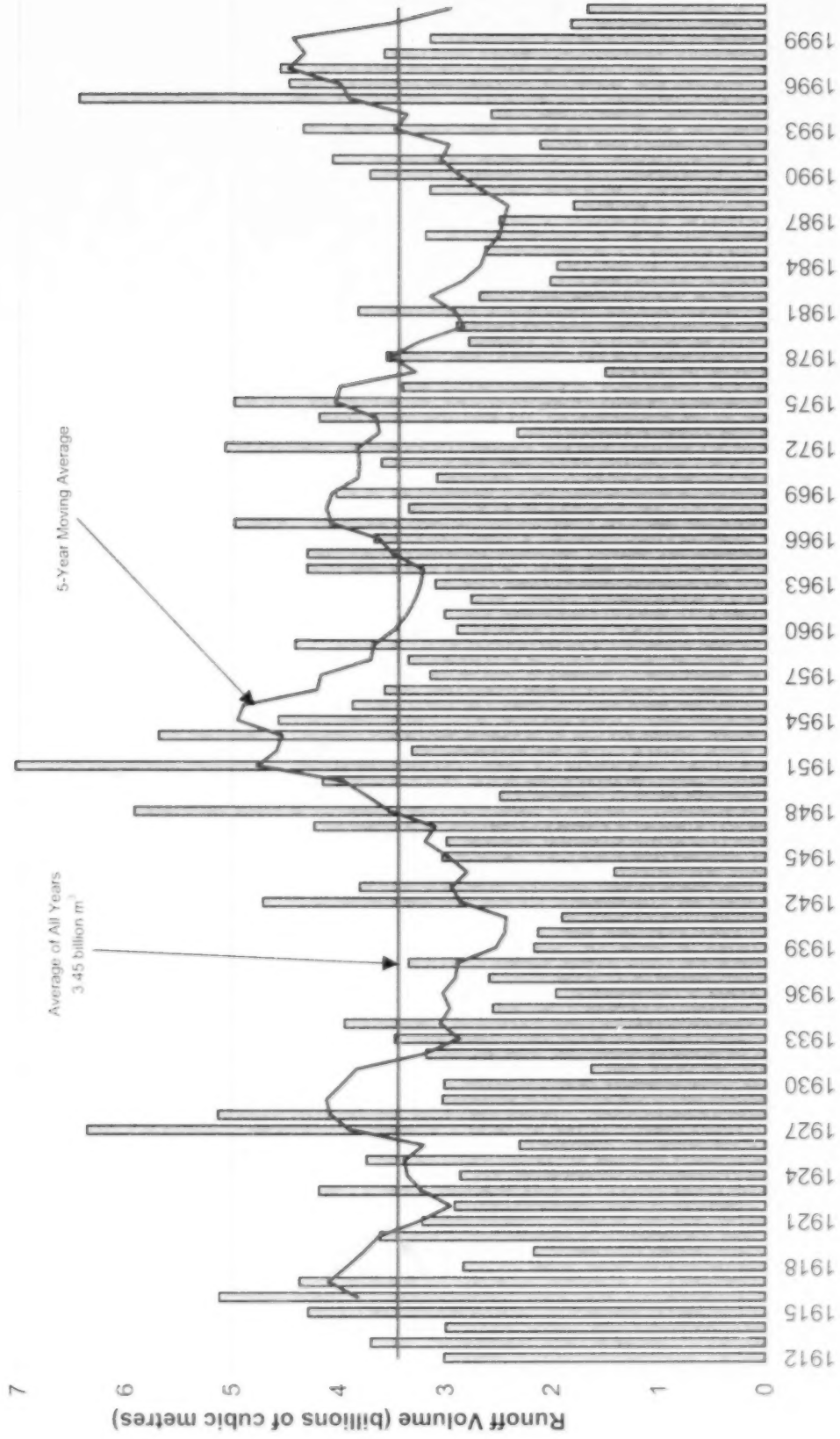


Recorded Annual Runoff Volume for the North Saskatchewan River at Edmonton (WSC # 05DF001)





Naturalized Annual Runoff Volume for the Oldman River near Lethbridge





Recorded Annual Runoff Volume for the Oldman River near Lethbridge (WSC # 05AD007)



8



7

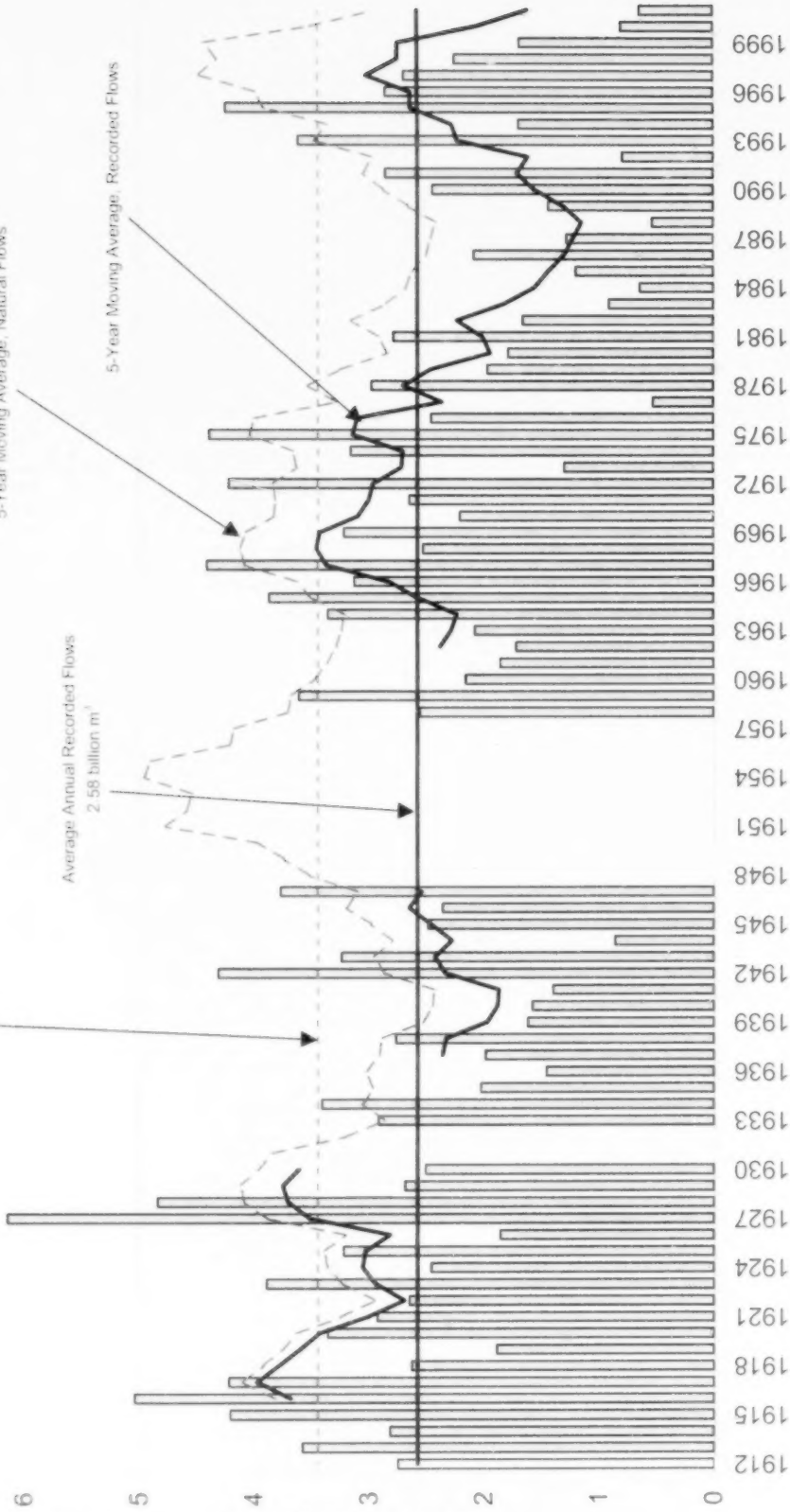
Average Annual Natural Flows
3.45 billion m³

6

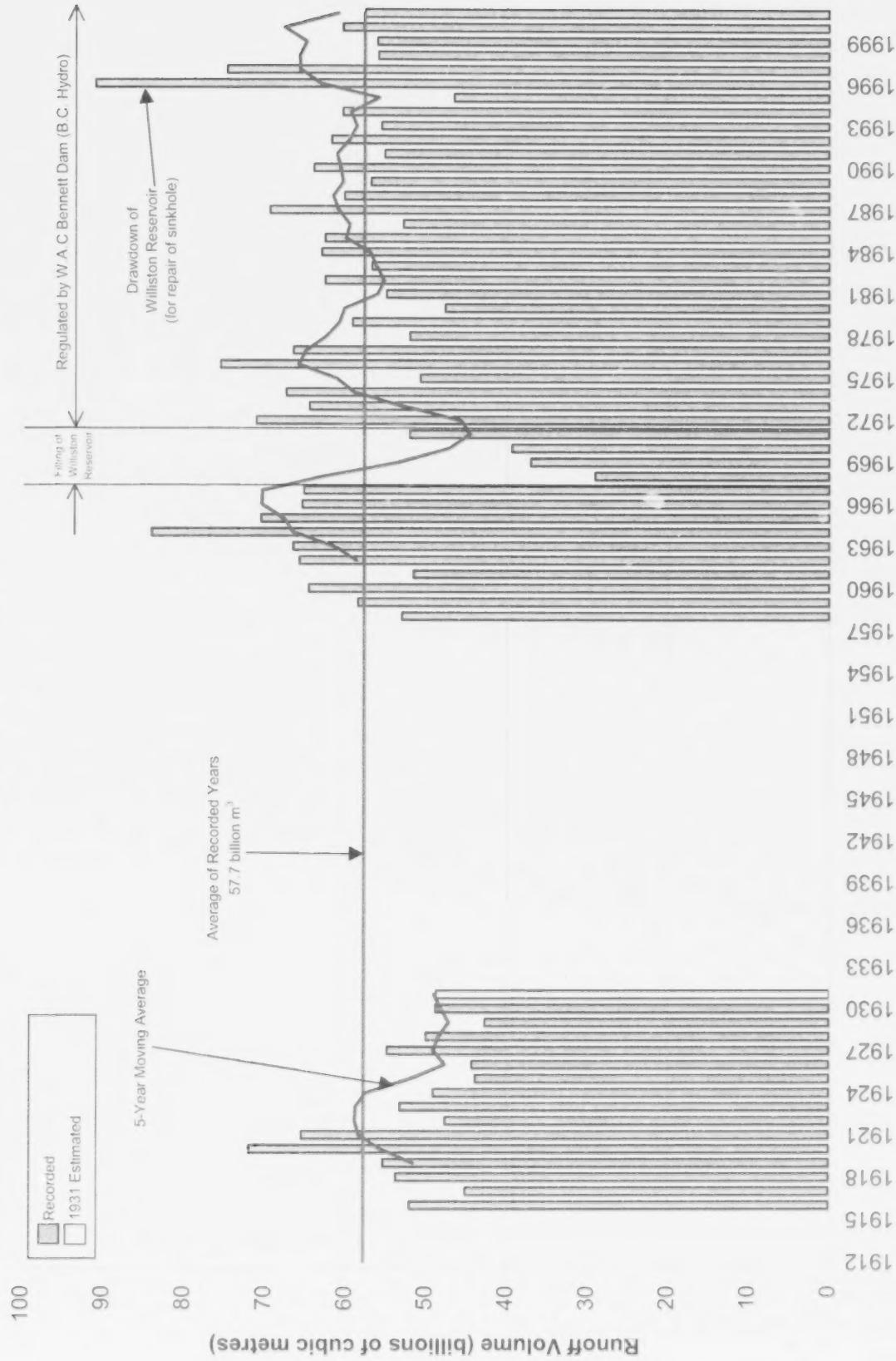
Average Annual Recorded Flows
2.58 billion m³

5-Year Moving Average, Natural Flows
5-Year Moving Average, Recorded Flows

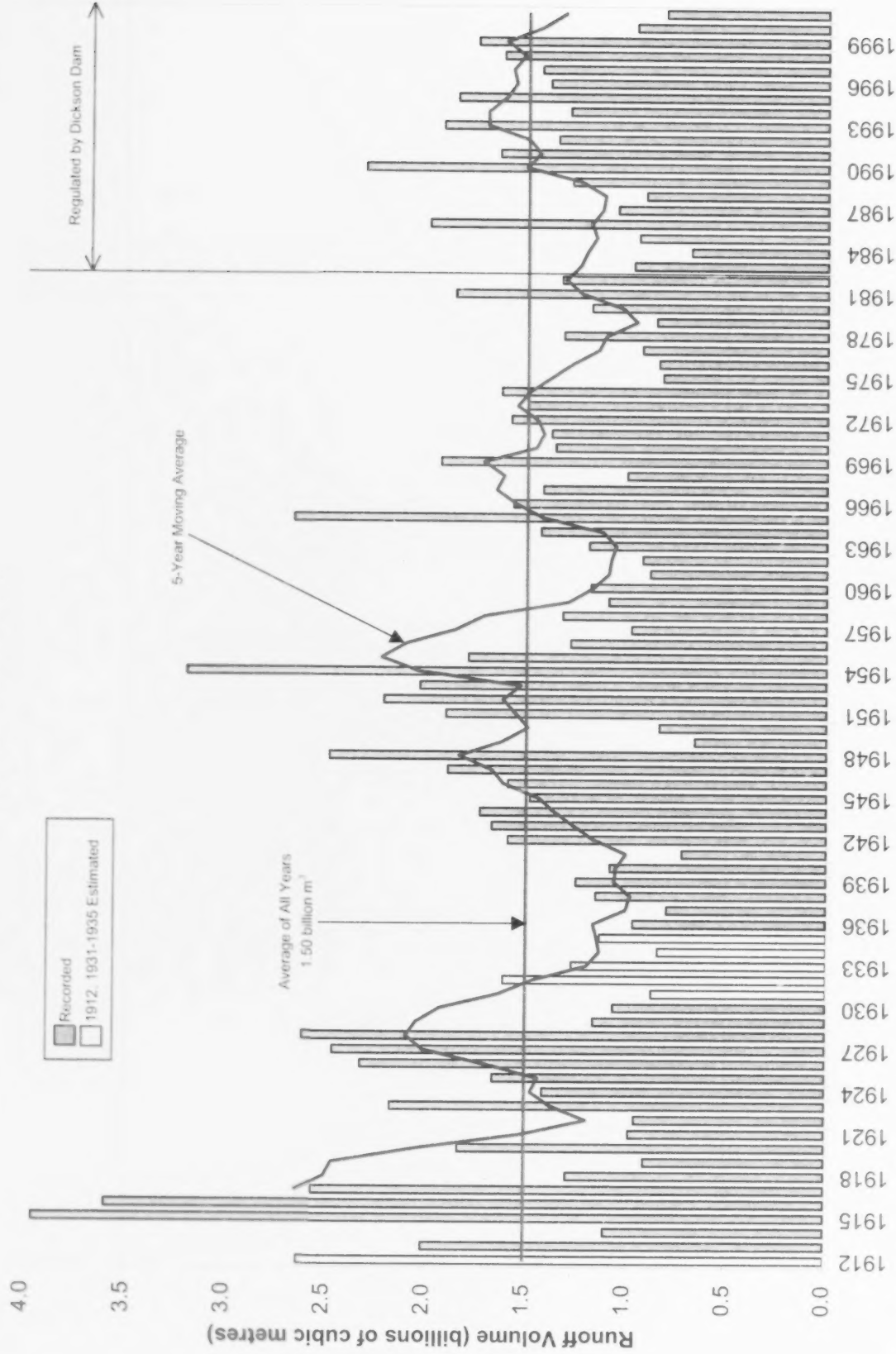
Runoff Volume (billions of cubic metres)



Recorded Annual Runoff Volume for the Peace River at Peace River (WSC # 07HA0001)

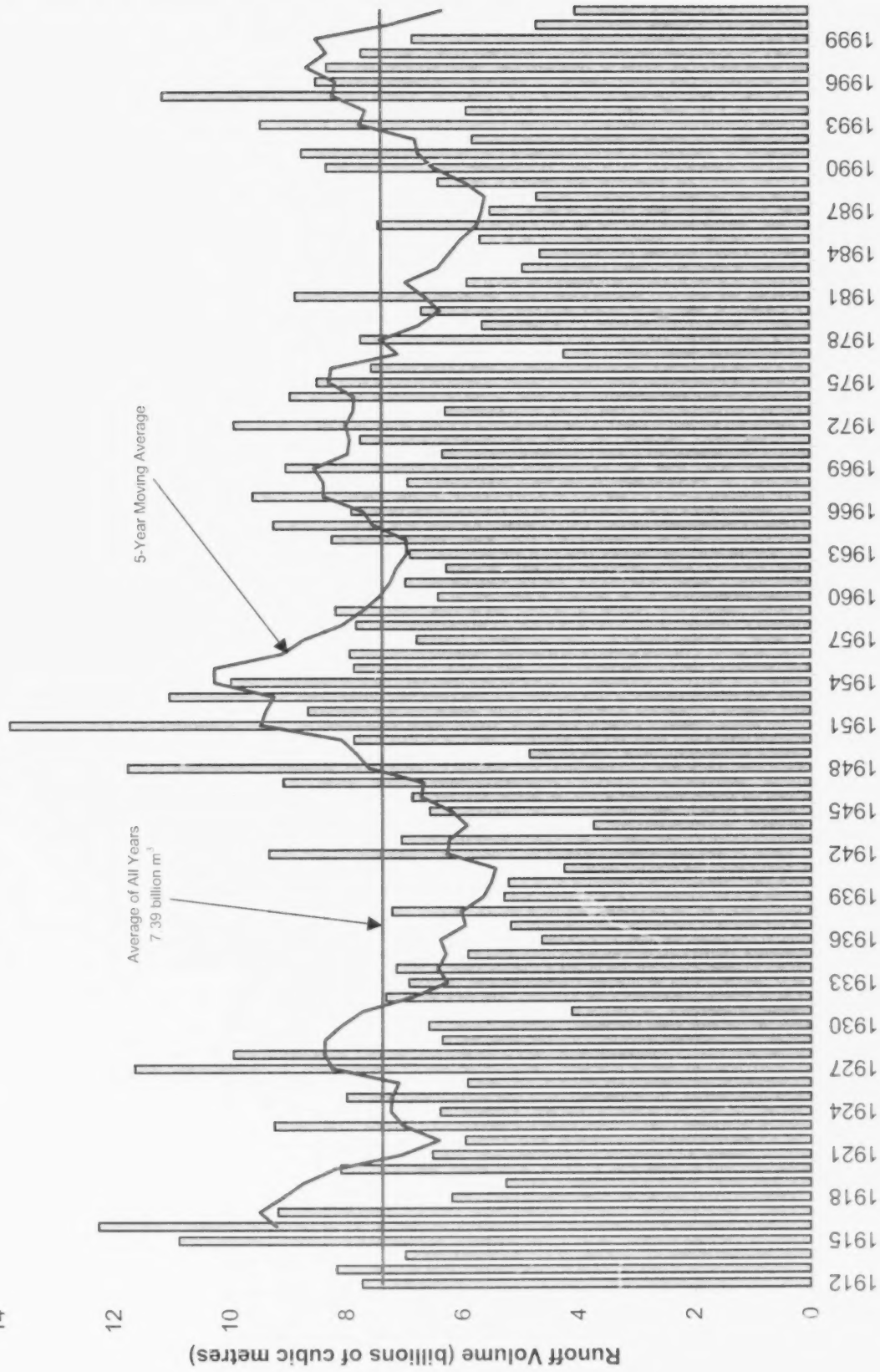


Recorded Annual Runoff Volume for the Red Deer River at Red Deer (WSC # 05CC002)





Naturalized Annual Runoff Volume for the South Saskatchewan River at Medicine Hat





Recorded Annual Runoff Volume for the South Saskatchewan River at Medicine Hat (WSC # 05AJ001)



14

